

## Anomalous top magnetic couplings

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**Abstract.** The real and imaginary parts of the one-loop electroweak contributions to the left and right tensorial anomalous couplings of the  $tbW$  vertex in the Standard Model (SM) are computed.

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Top quark physics at the Large Hadron Collider (LHC) is an important scenario for testing physics above the electroweak scale [1,2]. Some effects related to the top anomalous couplings, both in the  $t \rightarrow bW^+$  polarized branching fractions and in single top production at the Tevatron and at the LHC, have already been studied in recent years. One-loop QCD and electroweak contributions to the  $tbW$  vertex have been studied in the frame of the Standard Model (SM) [3]. The explicit dependence of the polarized branching fractions on the anomalous couplings have been computed in refs [4,5].

We compute the electroweak SM contribution to the left and right ‘magnetic’ tensorial couplings of the  $tbW$  vertex. We found that the electroweak contribution is also at the level of 10% with respect to the leading gluon exchange. For on-shell particles, the amplitude  $\mathcal{M}_{tbW}$  can be written in the following way:

$$\mathcal{M}_{tbW^+} = -\frac{e}{\sin \theta_W \sqrt{2}} \epsilon^{\mu*} \bar{u}_b \left[ \frac{i\sigma_{\mu\nu} q^\nu}{m_W} (g_L P_L + g_R P_R) \right] u_t. \quad (1)$$

One-loop QCD gluon exchange contribution to  $g_R$  was computed in ref. [6],  $g_R^{\text{QCD}} = -6.61 \times 10^{-3}$ . The sensitivity to  $g_R$  will be accessible to the LHC experiments [2,5]. The left tensorial term couples a right  $b$ -quark and thus it is proportional to  $m_b$ . Then, constraints on  $g_L$  are stronger than  $g_R$  due to the chiral  $m_t/m_b$  factor.

Indirect limits on  $g_L$  and  $g_R$  can be obtained from  $b \rightarrow s\gamma$  [7]. The results from the analysis given in refs [8] and [9] are given in the first line of table 1; the second and third lines show  $g_L$  and  $g_R$  limits predicted for the future LHC data [5]. The LHC will improve the sensitivity to  $g_R$  by an order of magnitude compared to bounds from  $b \rightarrow s\gamma$ . In the same way as it is done in Tau physics [10], new asymmetry observables derived from

**Table 1.** Bounds on  $g_R$  and  $g_L$ .

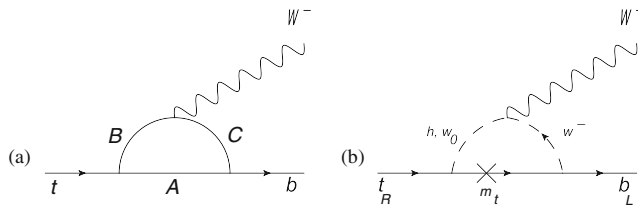
Reference		$g_R$ Bound	$g_L$ Bound
$bs\gamma$	95% CL	$-0.15 < g_R < 0.57$	$-0.0015 < g_L < 0.0004$
Future LHC data	$2\sigma$	$-0.026 \leq g_R \leq 0.031$	$-0.058 \leq g_L \leq 0.026$
Future LHC data	$1\sigma$	$-0.012 \leq g_R \leq 0.024$	$-0.16 \leq g_L \leq 0.16$
		$g_R$ Discovery limit	$g_L$ Discovery limit
Helicity fractions of the $W$	$3\sigma$	$ \text{Re}(g_R)  \geq 0.056$	$\text{Re}(g_L) \geq 0.051$ or $\text{Re}(g_L) \leq -0.083$
$bs\gamma$	$3\sigma$	$ \text{Im}(g_R)  \geq 0.115$ $\text{Re}(g_R) \geq 0.76$ or $\text{Re}(g_R) \leq -0.33$	$ \text{Im}(g_L)  \geq 0.065$ $\text{Re}(g_L) \geq 0.0009$ or $\text{Re}(g_L) \leq -0.0019$  $ \text{Im}(g_L)  \geq 0.006$

helicity fractions for polarized  $W$  were defined for polarized top decays; the exclusion intervals derived from these observables are shown in the fourth line of table 1. As a reference for the comparison with the LHC, they also derived as  $3\sigma$  discovery limits from  $b \rightarrow s\gamma$  in ref. [9]; this is shown in the last line of table 1.

At one loop in the SM, there is only one topology for the diagrams that contribute to the anomalous  $g_R$  and  $g_L$ : this is shown in figure 1a. For  $g_R$  there are two diagrams that have a leading  $m_t$ -mass. They are the ones in figure 1b with  $thW$  and  $tw_0W$  circulating in the loop, where  $h$  is the Higgs boson and  $w_0$  is the unphysical  $Z$ -boson. These two diagrams have top mass insertions that give a mass dependence which is of the order  $1/r_W^2 = 1/(m_W/m_t)^2$  with respect to the other diagrams. Some diagrams, like  $bWZ$  for example, contribute to the imaginary part of  $g_R$ .

The result for each contribution of the diagrams to  $g_R$  and  $g_L$  is given in table 2, with  $m_h = 150$  GeV. The final result for the one-loop electroweak correction is

$$g_R^{\text{EW}} = -(0.56 + 1.23i) \times 10^{-3}, \quad g_L^{\text{EW}} = -(0.92 + 0.14i) \times 10^{-4}. \quad (2)$$



**Figure 1.** (a) Topology of the one-loop SM Feynman diagrams for the quantum correction to the  $t \rightarrow bW^+$  decay. (b) Leading order diagrams for  $g_R$  in the large  $m_t$  limit.

**Table 2.** Electroweak contributions to  $g_R$  and  $g_L$ .

Diagram	$g_R \times 10^3$	$g_L \times 10^3$
$tZW$	-1.176	-0.0141
$thW$	0.220	0
$tw^0w^-$	0.344	0.0051
$hw^-$	0.462	-0.0088
$tZw^-$	-0.050	-0.0012
$t\gamma W + t\gamma w^-$	0.572	-0.0094
$bWZ$	$-0.623 - 0.664i$	$-0.0201 - 0.0214i$
$bWh$	0	$0.0086 - 0.0120i$
$bw^+w^0$	$(1.5 + 11.0i) \times 10^{-4}$	$-0.0029 - 0.0167i$
$bw^+h$	$(-4.3 + 8.6i) \times 10^{-4}$	$-0.0019 + 0.0111i$
$bw^+Z$	$-0.088 - 0.062i$	$-0.00039 - 0.00028i$
$bW\gamma + bw^+\gamma$	$0.114 - 0.509i$	$-0.0270 + 0.0250i$
$Ztb$	-0.397	-0.0067
$\gamma tb$	0.068	0.0115
$w^0tb$	$-6.8 \times 10^{-4}$	-0.0109
$htb$	$-6.2 \times 10^{-4}$	-0.0135
$\Sigma(EW)$	$-0.56 - 1.23i$	$-(0.092 + 0.014i)$
$gtb$	-6.61	-1.12

We note that for  $g_L^{\text{EW}}$  is 8% of  $g_L^g$ , and also that the CP violation has its origin in the electroweak diagrams. These values are to be compared with the gluon contribution that is the dominant one:

$$g_R^g = -6.61 \times 10^{-3}, \quad g_L^g = -1.12 \times 10^{-3}. \quad (3)$$

The final result for the one-loop computation in the SM is the sum of eqs (2) and (3):

$$g_R^{\text{SM}} = -(7.17 + 1.23i) \times 10^{-3}, \quad g_L^{\text{SM}} = -(1.21 + 0.01i) \times 10^{-3}. \quad (4)$$

The real part for the one-loop electroweak quantum correction for  $g_R$  is 8% of the leading gluon-exchange contribution. Note that the imaginary part is 17% of the one-loop  $\text{Re}(g_R^{\text{SM}})$ .

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## References

- [1] M Beneke *et al*, hep-ph/0003033
- [2] W Bernreuther, *J. Phys.* **GG35**, 083001 (2008)  
E Boos, L Dudko and T Ohl, *Eur. Phys. J.* **C11**, 473 (1999)  
J A Aguilar-Saavedra, *Nucl. Phys.* **B804**, 160 (2008)

- [3] H S Do *et al*, *Phys. Rev.* **D67**, 091501 (2003)
- [4] C R Chen, F Larios and C P Yuan, *Phys. Lett.* **B631**, 126 (2005)  
Gabriel A Gonzalez-Sprinberg, Roberto Martinez and Jorge Vidal, *J. High Energy Phys.* **1107**, 094 (2011)
- [5] F del Águila and J A Aguilar-Saavedra, *Phys. Rev.* **D67**, 014009 (2003)  
J A Aguilar-Saavedra *et al*, *Eur. Phys. J.* **C804**, 160 (2008)  
J A Aguilar-Saavedra *et al*, *Eur. Phys. J.* **C53**, 689 (2008)  
J Bernabéu and J A Aguilar-Saavedra, *Nucl. Phys.* **B840**, 349 (2010)
- [6] C S Li, R J Oakes and T C Yuan, *Phys. Rev.* **D43**, 3759 (1991)
- [7] M Jezabek and J H Kuhn, *Phys. Rev.* **D48**, 1910 (1993)  
A Czarnecki, *Phys. Lett.* **B252**, 467 (1990)  
C S Li, R J Oakes and T C Yuan, *Phys. Rev.* **D43**, 3759 (1991)
- [8] J Alwall *et al*, *Eur. Phys. J.* **C49**, 791 (2007)
- [9] B Grzadkowski and M Misiak, *Phys. Rev.* **D78**, 077501 (2008)
- [10] J Bernabéu, G A González-Sprinberg and J Vidal, *Phys. Lett.* **B326**, 168 (1994)  
J Bernabéu *et al*, *Nucl. Phys.* **B436**, 474 (1995)